

# **GRAVITATIONAL INSTABILITY ON PROPAGATION OF MHD WAVES IN ASTROPHYSICAL PLASMA**

**Alemayehu Mengesha Cherkos<sup>1,2</sup> AND S. B. Tessema <sup>1,2</sup>**

<sup>1</sup>. Entoto Astronomical Observatory and Space Science Research Center, P.O. Box 8412, Addis Ababa, Ethiopia

<sup>2</sup>. Department of Physics, Kotebe College, P.O. Box 31248, Addis Ababa, Ethiopia  
(alexye9@yahoo.com)

Abstract

We determine the general dispersion relation for the propagation of magnetohydrodynamic (MHD) waves in astrophysical plasma by considering the effect of gravitational instability and viscosity with anisotropic pressure tensor and heat-conducting plasma. Basic MHD equations have been derived and linearized by the method of perturbation to develop the general form of dispersion relation equation. Our result indicates that the transverse propagation of waves in such a plasma is affected by the inclusion of heat conduction. For wave propagation, parallel to the magnetic field direction, we find that the fairhose mode is unaffected, whereas the mode corresponding to the gravitational instability is modified in astrophysical plasma with anisotropic pressure tensor being stable in the presence of viscosity and strong magnetic field at considerable wavelength.

## Study of solar cycle variation and its impact on critical frequency of F2 layer

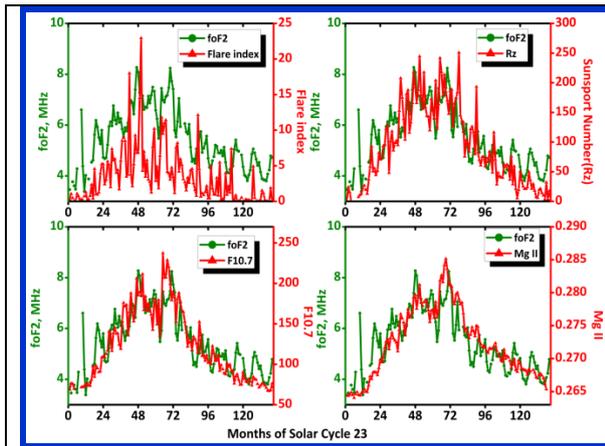
P. K. Purohit<sup>1</sup> and Roshni Atulkar<sup>1</sup>

<sup>1</sup>National Institute of Technical Teachers' Training and Research, Bhopal – 462002, MP, India.

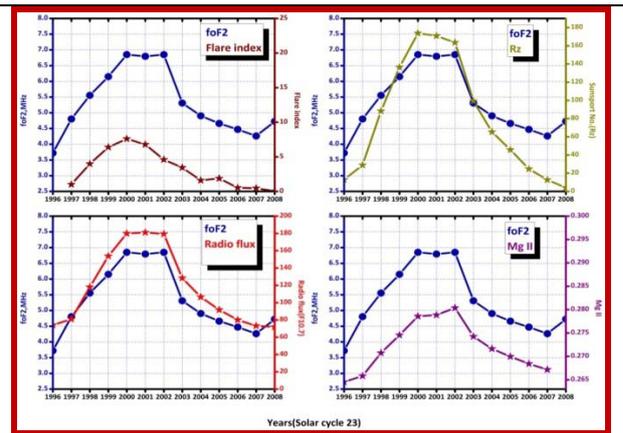
The period of approximately 11 year cycle of solar activity is characterized by the rise and fall in the numbers and surface area of sunspots. We observed a number of other solar activity indices, including the 10.7 cm radio flux, solar Mg II core to wing ratio, relative sunspot number Rz and solar flare index geomagnetic activity that vary in association with the sunspots for solar cycles 23 (1996–2008). This paper presents an analysis of the F-region variability of the ionospheric F2 layer critical frequency (foF2) at Australian mid latitude ionosonde station, Hobart (42.88° S and 147.32° E) during the period 1996 – 2008 of solar cycle 23. The diurnal, monthly, and yearly characteristics of ionospheric F-region parameter foF2 have been studied in detail. We also compared the dependence of foF2 on solar activity indices by using a correlation analysis, and showed a significant linear relationship between the foF2 values and Solar indices. The foF2 variation is strongly influenced by solar activity with about an 11-year solar cycle from the solar maximum to solar minimum.

Table 1. Correlation of foF2 with solar indices during different phases of solar cycle 23.

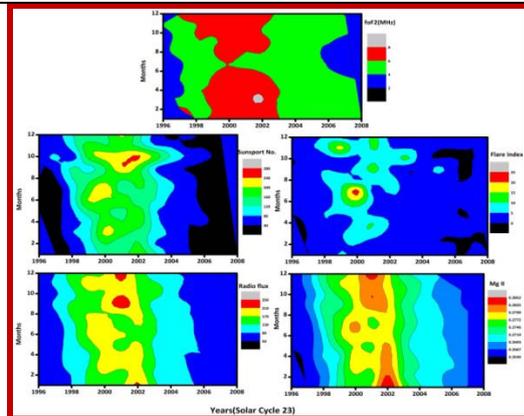
Geomagnetic Indices Vs Fof2	Correlation
Flare Index-foF2	0.85
Rz-foF2	0.92
F10.7-foF2	0.93
Mg II c/w-foF2	0.88



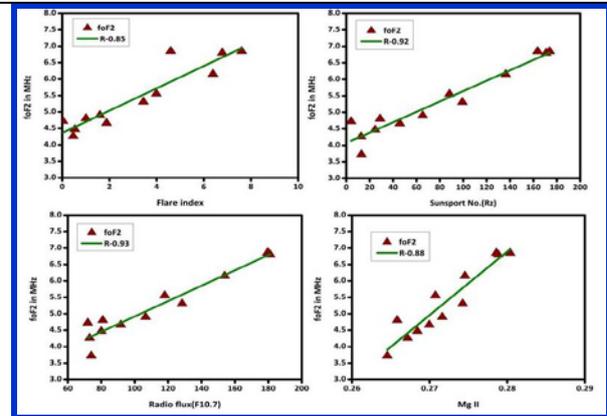
**Figure – 1:** Monthly variation of solar indices with critical frequency foF2 during Solar Cycle 23.



**Figure–2:** Annual variation of solar indices with critical frequency foF2 during Solar Cycle 23.



**Figure-3:** Behavior of critical frequency foF2 and solar indices during the solar cycle 23.



**Figure – 4:** Scatter and Correlation of foF2 with Flare index, sunspot number (Rz), Radio flux (F10.7) and Mg II core to wing ratio during the solar cycle 23.

## References

- [1] Adler N O et al 1997., Solar cycle length variation: its relation with ionospheric parameters, Journal of Atmospheric and Solar-Terrestrial Physics, Vol. 59, No. 2, pp. 159-162. [2] Bruevich E.A. et al 2011., Changed Relation Between Radio Flux F10.7 And Some Solar Activity Indices During Cycles 21 – 23, Solar and Stellar Astrophysics (astro-ph.SR). [3] Bilitza D. 2000 The importance of EUV indices for the international reference ionosphere. *Phys Chem Earth (C)*, 25: 515–521 [4] Sethi N. K., Goel et al 2002 Solar cycle variations of foF2 from IGY to 1990, *Ann. Geophys.*, 20, 1677 – 1685.

## Study of magnetic storm effects on the variation of TEC over low, mid and high latitude station

Roshni Atulkar<sup>1</sup> and P. K. Purohit<sup>1</sup>

<sup>1</sup>National Institute of Technical Teachers' Training and Research, Bhopal – 462002, MP, India.

The ionosphere is very important because of its influence on the passage of radio waves. Total electron content (TEC) is a key ionospheric parameter that describes the major impact of the ionosphere on the propagation of radio waves which are crucial for terrestrial and space communication. The present investigation is dedicated to study the latitudinal variation of ionosphere. The study is carried out by taking three stations one each in low, mid and high latitude regions namely IISC, Bangalore, India (13.020 N, 77.570E), GUAO, Urumqi, China (43.820N, 87.600E) and NYAL, NY-Alesund, Norway (78.920N, 11.860E) respectively. To study the changes in the ionosphere at three selected station we have considered the GPS observations. The GPS derived TEC values have been collected from the SOPAC (Scripps Orbits and Permanent Array Center) data archive of the IGS (International GPS service). We studied the behaviour of ionospheric Total Electron Content (TEC) during the geomagnetic storms. We have selected 5 intense geomagnetic storms ( $Dst \leq -100nT$ ) that were observed during the year 2012. From our analysis we observed that the effect of geomagnetic storms on VTEC is highest at low latitude, moderate at mid latitude and low at high latitude.

Table 1. Catalogue of all the five selected intense geomagnetic storm events along with Peak Dst.

Event Date	Peak Dst(Min.)
9 March 2012	-143nT
24 April 2012	-104nT
15 July 2012	-133nT
1 October 2012	-133nT
14 November 2012	-109nT

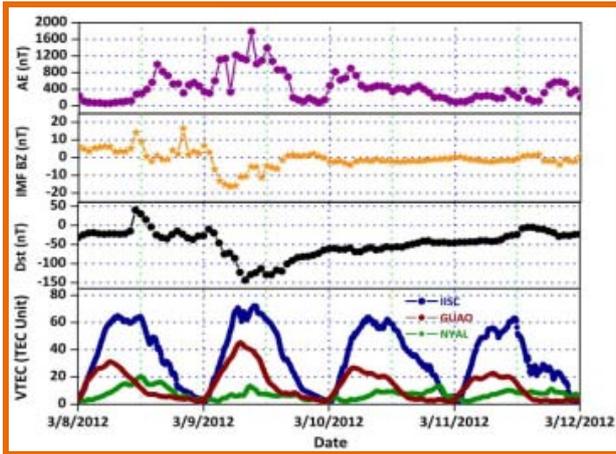


Figure 1:

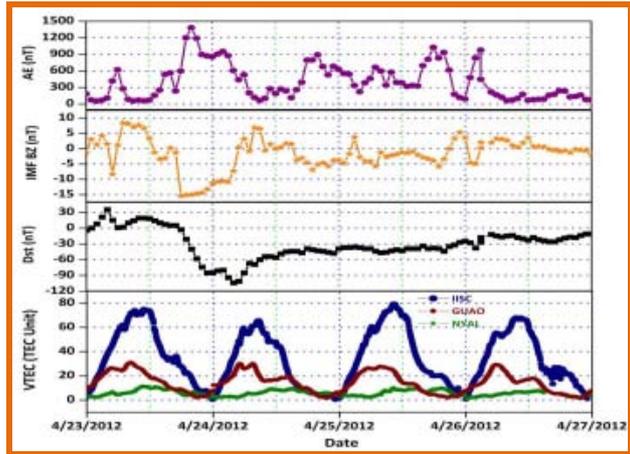


Figure 2

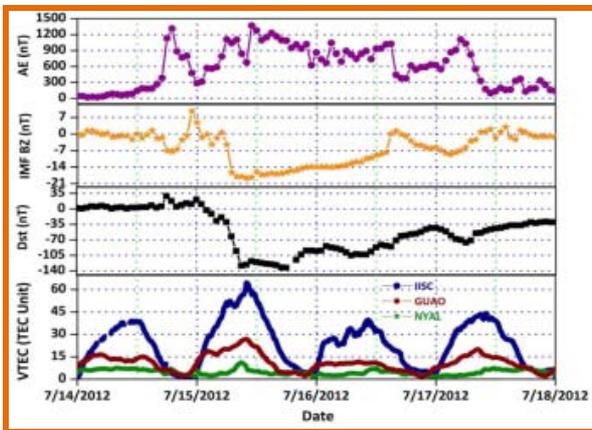


Figure 3

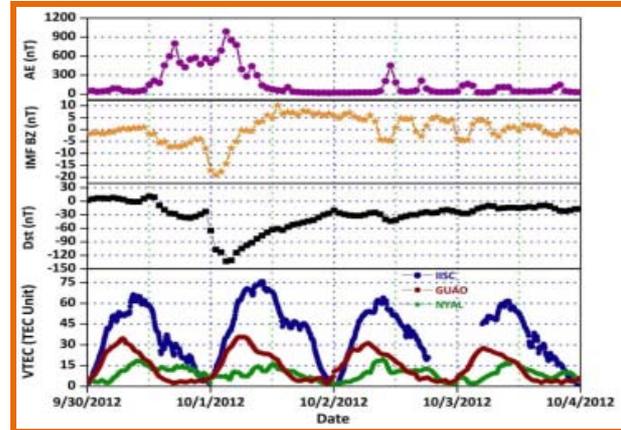


Figure 4

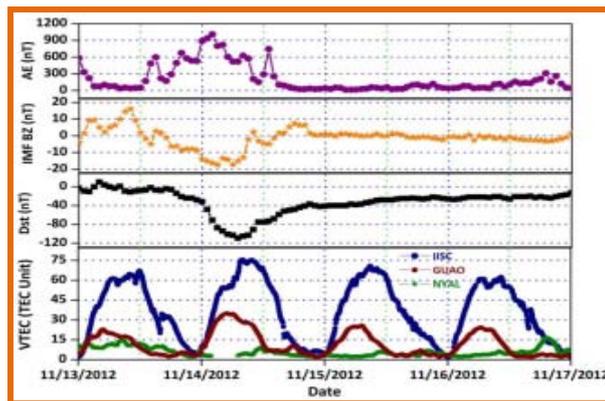


Figure 5

Figure 1, 2, 3, 4 and 5. Plot of temporal evolution of ionospheric VTEC along with Dst, IMF Bz and AE during the geomagnetic storm of 9 March, 24 April, 15 July, 1 October, and 14 November 2012.

## References

- [1] Akasofu S-I. (1981) Relationships between the AE and Dst indices during geomagnetic storms. *J. Geophys. Res.* 86:4820–4822. [2] Mendillo M, et al. 1970, Ionospheric storms at midlatitudes. *Radio Sci.* 5:895–898. and, doi: 10.1029/RS005i006p00895. [3] Titheridge J E et al. 1988. A comparison of Northern and Southern Hemisphere TEC storm behaviour. *J. Atmos. Terr. Phys.* 50:763–780.

## **Moon-Earth: global basaltic effusions, their different ages, common chemical trends (alkalinity, iron content)**

Gennady G. Kochemasov

IGEM of the Russian Academy of Sciences, 35 Staromonetny, 119017 Moscow,  
[kochem.36@mail.ru](mailto:kochem.36@mail.ru)

Global basaltic covers are very characteristic phenomena in the inner solar system. Basaltic effusions of different ages and compositions originated in asthenospheric layers of the planetary mantles. To heat and melt some parts of the mantle, a part of enormous mechanical energy of orbiting cosmic bodies was transferred to the heat energy.

“Orbits make structures” – a main point of the new wave planetology based on one important property of the Keplerian elliptical planetary orbits [2, 3]. The ellipticity implies periodical changes of accelerations and, thus, orbital forces structuring cosmic bodies. The Earth and the Moon sharing the same circumsolar orbit have similar main structural features. Among them there are terrestrial Oceans and lunar Basins. The most obvious are two tectonic triads: Pacific Ocean – Malay Archipelago – Indian Ocean on Earth and Procellarum Basin – Mare Orientale – SPA Basin on the Moon. The planetary depressions of both bodies are covered with basalts, but basaltic effusions are drastically different in age: the AR on Moon and Mz-Cz on Earth. These ages well correlate with the bodies masses. The more massive and inert Earth has heated and melted mantle much later (The Newton’s law of inertia). Energy of movement transfers to the heat energy.

The both cosmic bodies, as well as the rest of them, are tectonically dichotomous. Their subsided hemispheres, for keeping angular momentum of hemispheres equal, are filled with dense basaltic material. But times of the fillings are significantly different.

The Earth-Moon system expands with time, that is increases its angular momentum. A natural response to it is in slowing down rotation of both bodies diminishing their angular momentum (action - opposite action). Diminishing momenta are compensated by melting and uplifting to surfaces dense basaltic material. But on the Moon it happened much earlier (4.5-3 billion years ago) because of diminished inertia of the small mass satellite. At much larger and massive with large inertia Earth this process was significantly “delayed” in time.(Mz-Cz). Earth is 81 times more massive than Moon. (3-4.5 billions) :  $81 = 37-55$  million years. According to this calculation, a “peak” of the basaltic reaction of Earth, filling in by basalts the oceanic depressions is in the boundary of Mesozoic and Cenozoic [3]].

Despite of enormous age differences between lunar and terrestrial basaltic covers (billions of years!) some common chemical shift of their compositions is notable and significant. Let us compare Procellarum Basin and Pacific Ocean basalts. The oldest parts of their covers occur mainly in the West of Procellarum (KREEP) and SW of the Pacific (Ontong Java Plateau – the largest LIP of Earth). Potassium, phosphorus, rare earths, thorium enrich the older lunar KREEP basalts. The older terrestrial oceanic Ontong Java basalts (Cretaceous age-about 122 mln. y) also show “KREEP trend”. They belong to E-MORBs and have elevated values of potassium, lithium, chlorine, REE, thorium. Elevated Fe/Mg (and siderophile platinum group elements) also is in Ontong Java basalts [1]. All these chemical peculiarities distinguish them from the younger N-MORBs of other parts of the Pacific Ocean (EPR, for example). As all considered basalt melts of both bodies originate in asthenospheres, the older parts of these melts derive from relatively earlier “cool” asthenosphere. It means that only easily melted alkali and iron rich parts were involved in the process. Later on, significantly heated asthenospheres produced enormous volumes of chemically different (less alkaline and more magnesian) basalts. In this sense, rather impressive is a comparison of the lunar iron and

thorium geochemical maps stressing coincidence of their anomalies in the Procellarum KREEP terrain area (Fig. 1, 2).

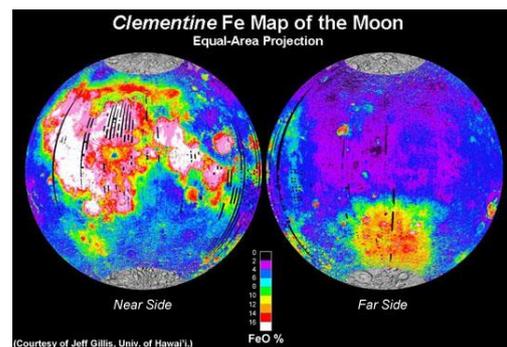
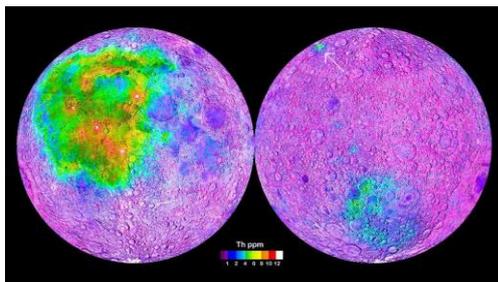
The considered time development of basaltic magmatism could be paralleled with the development of alkaline terrestrial magmatism. Its earlier older parts often are more alkaline than later Cenozoic parts. Famous large agpaitic massifs are mainly Proterozoic-Paleozoic in age. Again, early “cold” asthenosphere produces more easily melted relatively small alkaline parts than the later “hot” asthenosphere making large volumes of deeply melted more magnesian less alkaline ones.

#### References:

[1] Ely J.C. and Neal C.R. (2003) Using platinum-group elements to investigate the origin of the Ontong Java Plateau, SW Pacific // *Chemical Geology*, v. 196, 235-25

[2] Kochemasov G.G. (2016) The Moon and Phobos: specific responses of two satellites moving off and nearer their respective planets // *DPS 48/EPSC 11*, Pasadena, Oct. 16-21, 2016, *Bulletin of the American Astronomical Society*, 2016, vol. 48, # 7, p. 175, Abstract 318.08, Session 318: Formation and Evolution of Planets and Satellites Posters.

[3] Kochemasov G.G. (2017) New planetology and geology: tectonic identity and principal difference of terrestrial oceans and lunar basins // *New Concepts in Global Tectonics (NCGT) Journal*, 2017, V. 5, # 1, p 131-133.



# On the bulk silicate composition of carbonaceous chondrites

P. Futó<sup>1</sup>, A. Gucsik<sup>2</sup>

<sup>1</sup> University of Debrecen, Department of Mineralogy and Geology, Debrecen, Egyetem tér 1. H-4032, Hungary  
([dvision@citromail.hu](mailto:dvision@citromail.hu))

<sup>2</sup> Wigner Research Center for Physics, Hungarian Academy of Sciences, Konkoly Thege Miklós 29-33., Budapest, Hungary

## Introduction:

The bulk compositions of the stony meteorites have been dominated by silicates and oxides. The one part of meteoritic minerals came through different grade of the chemical and/or physical transformations during the formation of the Solar-System. There are ancient mineral constituents, which survived the early stage of the evolution of the Solar-System and they appears original form: presolar dust grains. Primitive meteorites contain presolar dust grains: silicates, oxides, nanodiamonds, silicon carbide graphite, silicon nitride. The dominant sources of dust grains are the AGB stars and supernovae. The presolar silicate abundance is greater than the abundances of other presolar minerals [1].

Carbonaceous chondrites (CC, c-chondrites) are primitive meteorites with significant silicate and oxide amounts, some of them contain a relatively larger amount of elemental carbon (diamonds, graphite) and carbon-based compounds (silicon-carbide, different organic compounds). They are composed mostly of chondrules, inclusions and the fine-grained matrix. C-chondrites can be classified according to that their parent bodies formed in different regions of the early Solar-system. Accordingly, different CC-groups may distinguished as CI, CM, CV, CO, CR, CK, and CH type chondrites [2]. The groups are further divided into different subgroups.

Similarities and significant differences also appears in the abundances of given compounds in the different chondrites depending on the formation conditions of their parent bodies. For instance, the bulk composition of Allende matrix is Fe-rich obtained by Inoue et al. [3], the CM2 Murchison meteorite is an organic rich carbonaceous chondrite [4]. Chemical similarities appear between CM and CO chondrite chondrules [5], while considerable differences show the Murchison (CM2) and the Allende (CV3) chondrites in carbon content of the matrix.

In carbonaceous chondrites, highly forsteritic ( $Mg_2SiO_4$ ) olivine can be found for example in the chondrules, in the (Amoebid Olivine Aggregates (AOA) and in the grains and aggregates embedded in the matrix. Fayalitic olivine ( $Fe_2SiO_4$ ) is also identified in the mineral structures, but its amount is smaller than that of the forsterite. Enstatite ( $MgSiO_3$ ) and ferrosillite ( $FeSiO_3$ ) are also known in the mineral textures of chondrites.

*Bulk silicate composition of c-chondrites* The investigation for characteristics of silicates based on in detail the Kaba primitive CV3 c-chondrite [6], otherwise we studied the pure matrix material of the Allende CV3 c-chondrite with the concerning data utilized from the results of Inoue N. et al. 2004 [3]. We determined the Mg/Fe ratio in the silicates and the results have been summarized in the Table 1.

Kaba (CV3) mineral structure	Mineral sample	FeO(wt%)	MgO(wt%)	Mg/Fe
<b>Porphyritic chondrule</b>	Forsterite Fo1-1	0.30	55	Mg0.993Fe0.007
<b>Granular ol-px chondrule</b>	Forsterite Fo3-1	0.89	54.99	Mg0.98 Fe0.02
	Forsterite Fo3-2	1.02	54.70	Mg0.976Fe0.024
<b>Isolated olivine grain</b>	Forsterite Fo8-2	0.21	56.91	Mg0.995Fe0.005
<b>Comlicated aggregate</b>	Fayalite Fa9-2	68.05	0.26	Mg0.003Fe0.997

Allende (CV3)				
Pure matrix	A1	36.60	19.19	Mg0.407Fe0.593

Table 1. The FeO and the MgO abundances in different mineral structures of the Kaba meteorite (CV3) and in the bulk chemical composition of the matrix of the Allende (CV3) chondrite. The Mg/Fe ratio is calculated from the basic data that are taken from Gucsik A. et al. (2013) and from Inoue M. et al. (2004).

As seen in the Table 1, the mineral components of the Kaba meteorite is rich in highly forsteritic ( $Fo > 0.99$ ) olivines, while the bulk silicate composition of the Allende matrix enriched in iron. In fact, the mineral composition of chondritic meteorites has been dominated by silicates. The elemental abundances of chondrites approximately consistent with the cosmic abundances of elements and minerals. The high ratio of Mg, Si, and O in meteorites refers to the dominance of magnesium silicates for the case of chemical characteristics of the Galaxy as opposed to the abundances of Fe-, Ca-, Al-silicates.

**Summary:** The carbonaceous chondrites are known to have been dominated by silicates but they may contain carbonaceous mineral constituents in small amounts. The bulk composition of the planet-building materials in the most circumstellar environments is assumed to be chondritic-like.

## References

[1] Nguyen A. N. et al., Characterization of presolar silicate and oxide grains in primitive carbonaceous chondrites, *The Astrophysical Journal* 656, 1223-124, 2007. [2] Kallemeyn G.W. and J.T. Wasson, The compositional classification of chondrites—I. The carbonaceous chondrite groups, *Geochimica et Cosmochimica Acta*, 45(7), 1217-1230, 1981. [3] Inoue N. et al. EE abundances in the matrix of the Allende (CV) meteorite: Implications for matrix origin, *Meteoritics & Planetary Science* 39,599-608, 2004. [4] Kebukawa Y. et al., Kinetics of organic matter degradation in the Murchison meteorite for the evaluation of parent-body temperature history, *Meteoritics & Planetary Science* 45, 99-113, 2010. [5] Schrader D. L. and J. Davidson, CM and CO chondrites: A common parent body or asteroidal neighbors? Insights from chondrule silicates, *Geochimica et Cosmochimica Acta*, 214, 157-171, 2017. [6] Gucsik A. et al., Cathodoluminescence microscopy and spectroscopy of forsterite from Kaba meteorite: An application to the study of hydrothermal alteration of parent body, *Meteoritics & Planetary Science* 48, 2577-2596, 2013.

## NASA Curation Preparation for Ryugu Sample Returned by JAXA's Hayabusa2 Mission

Keiko Nakamura-Messenger<sup>1</sup>, Kevin Righter<sup>1</sup>, Christopher J. Snead<sup>2</sup>, Francis M. McCubbin<sup>1</sup>, Lisa F. Pace<sup>1</sup>, Ryan A. Zeigler<sup>1</sup>,  
& Cindy Evans<sup>1</sup>

<sup>1</sup>NASA Johnson Space Center, Houston, TX USA, <sup>2</sup>JETS at NASA Johnson Space Center, Houston, TX, USA

The NASA OSIRIS-REx and JAXA Hayabusa2 missions to near-Earth asteroids Bennu and Ryugu share similar mission goals of understanding the origins of primitive, organic-rich asteroids. Under an agreement between JAXA and NASA, there is an on-going and productive collaboration between science teams of Hayabusa2 [1] and OSIRIS-REx missions [2]. Under this agreement, a portion of each of the returned sample masses will be exchanged between the agencies and the scientific results of their study will be shared. NASA's portion of the returned Hayabusa2 sample, consisting of 10% of the returned mass, will be jointly separated by NASA and JAXA. The sample will be legally and physically transferred to NASA's dedicated Hayabusa2 curation facility at Johnson Space Center (JSC) no later than one year after the return of the Hayabusa2 sample to Earth (December 2020). The JSC Hayabusa2 curation cleanroom facility design has now been completed. In the same manner, JAXA will receive 0.5% of the total returned OSIRIS-REx sample (minimum required sample to return 60 g, maximum sample return capacity of 2 kg) from the rest of the specimen [2]. No later than one year after the return of the OSIRIS-REx sample to Earth (September 2023), legal, physical, and permanent custody of this sample subset will be transferred to JAXA, and the sample subset will be brought to JAXA's Extraterrestrial Sample Curation Center (ESCuC) at Institute of Space and Astronautical Science, Sagami City Japan.

Both the Hayabusa2 sample to be sent to NASA and the OSIRIS-REx sample to be sent to JAXA will be unprocessed and representative of the returned bulk sample. "Unprocessed" means that the sample will be handled in a way that minimizes chemical and physical changes to the sample, including avoidance of harsh radiation and heating environments such as electron beams and Raman microscopy. The exchange samples will also be protected from organic and other forms of contamination to the greatest extent possible. "Representative" means that the separated sample has, as well as can be determined on the unprocessed sample, very similar characteristics to the bulk returned sample, including grain size, color, and other physical properties readily determined by optical observation.

The overarching objectives of NASA's Hayabusa2 curation are to preserve and protect the returned Ryugu subset samples to maximize the science return. Curation scientists at JSC together with ESCuC members and the OSIRIS-REx science team have been working to identify requirements on contamination and sample environmental controls. The Hayabusa2 curation requirements can be categorized into the following nine major responsibilities: 1) Contamination control, 2) Curation procedures for solid and gas samples from Ryugu surfaces, 3) Clean laboratory design and construction, 4) Sample characterization for catalog (non-destructive organic-nonorganic lithology identification in a glovebox), 5) Sample distribution, and 6) long term curation activity. Many of the aspects of NASA Hayabusa2 curation for the Ryugu samples are already well developed and have strong heritage at JSC. Examples of existing knowledge and application in this area include ppb level organic residue monitoring of the gaseous curation grade nitrogen, precision cleaning of ultrapure water circulating in the clean labs, particle count monitoring, and metal material control for terrestrial trace element contamination control (Apollo, Genesis samples), and sample handling of small particles (cosmic dust, Stardust cometary particles, Hayabusa1 asteroid samples), to mm-cm sized rocks (Antarctic meteorites). The Hayabusa2 sample storage and handling facility at JSC have been co-designed with the OSIRIS-REx sample curation clean facility to protect the samples from contamination, cross-contamination, temperature excursions, and moisture that could alter the sample. The construction of the facility will start in 2018 [3].

As with every new extraterrestrial collection, returned primitive Ryugu samples bring special new requirements for potentially organic rich samples. Hayabusa2 mission will attempt to collect three samples from the surface of the asteroid in order to return a minimum of 100 mg of material. Prior to its third touchdown, Hayabusa2 will release an impactor to the asteroid that will create a small crater, possibly exposing more pristine materials from beneath the surface from which sample collection may be attempted. Each of the three samples may have different characteristics and they should be properly handled to preserve them. Hayabusa2 Science Team will attempt to extract the gas sample before opening the pneumatically sealed sample container. JSC will develop the gas sample curation and handling technique under our advanced curation activity [4].

**References:** [1] Watanabe S. et al. (2017) Space Science Reviews, 208, 3-16. [2] Lauretta D.S. et al. (2017) Space Science Reviews, in press. [3] Righter et al. (2017) this volume. [4] McCubbin F.M et al. (2017) this volume.

## Current status of developments by the collaboration team with ESCuC/JAXA for curation works and analysis of Hayabusa2 returned samples

M. Uesugi<sup>1</sup>, M. Ito<sup>2</sup>, N. Tomioka<sup>2</sup>, K. Uesugi<sup>1</sup>, A. Yamaguchi<sup>3</sup>, N. Imae<sup>3</sup>, T. Ohigashi<sup>4</sup>, Y. Karouji<sup>5</sup>, T. Yada<sup>6</sup>, and M. Abe<sup>6</sup>,  
<sup>1</sup>Japan Synchrotron Radiation Research Institute (JASRI/SPring-8) ([uesugi@spring8.or.jp](mailto:uesugi@spring8.or.jp)), <sup>2</sup>Japan Agency for Marine-Earth Science and Technology (JAMSTEC), <sup>3</sup>National Institute of Polar Research (NIPR), <sup>4</sup>Institute for Molecular Science (IMS),  
<sup>5</sup>Tokyo Metropolitan University, <sup>6</sup>Japan Aerospace Exploration Agency (JAXA).

Extraterrestrial sample curation center (ESCuC) of Japan aerospace exploration agency (JAXA) organized a special team for the development of techniques and devices for the handling, transfer and analysis of samples returned by Hayabusa2 spacecraft, from 2015 under the agreements of collaboration. The special team constitutes of members of institutes those having state-of-the-art analytical instruments and experiences of curatorial works of precious natural samples, but beyond the specialists of the extraterrestrial materials. Through the collaboration, we can introduce latest specialties and knowledges from diverse scientific and technological fields into the processes of analysis of Hayabusa2 returned samples [1,2].

So far, we finished the development sample transfer container for the inter-institute transfer, even international transfer of samples, without contamination of terrestrial materials and sample damages such as breaking and sample lost. We also evaluated the sealing performance of the container and confirmed that it has enough sealing performance against even positive pressure inside the container. The container, named as Facility to Facility Transfer Container (FFTC), is already available commercially.

Currently, the team members are working for (1) development of sample holders for the sample transfer in high cleanness environment, (2) development of devices for the atmosphere shielding environment for the sample handling, (3) development of sample holders applicable for multiple analytical methods, and (4) development of techniques for the evaluation of cleanness of those developed materials and environments. Although those devices and techniques are still under development, we already applied them for the analysis of samples in each institute, and evaluated its applicability and problem for the analysis of Hayabusa2 returned samples.

We also started development of new analytical protocols of extraterrestrial materials, which includes method of sample transfer, sample separation and data sharing, through the rehearsals of the curation works for the initial description of Hayabusa2-returned samples using extraterrestrial materials. Currently, 5 Antarctic micrometeorites provided by national institute of polar research (NIPR) were imaged by synchrotron radiation computed tomography (SR-CT) and x-ray diffraction (XRD) at SPring-8, and investigated by high resolution field emission scanning electron microscopy and energy dispersive spectroscopy (FE-SEM-EDS) system at institute for molecular sciences (IMS). Through the series of non-destructive analysis, we selected Antarctic micrometeorites those having similar characteristics of carbonaceous chondrites, and formed thin sections by focused ion beam (FIB) for the characterization of organic materials by scanning transmitted x-ray microscopy and near edge x-ray absorption fine structure analysis (STXM-NEXAFS) at IMS, high resolution analysis by transmission electron microscopy (TEM), and isotopic analysis of light elements such as hydrogen, carbon, nitrogen and oxygen by secondary ion mass spectrometry (SIMS) at Japan agency for marine-earth science and technology (JAMSTEC).

In order to make possible such large scale collaboration for the series of sample analysis between institutes, we need to evaluate sample damages and contaminations through the analysis, and develop the methods for cleaning of sample holder and protocols for suppressing sample damages, as well as sample transfer system. Sample holders are already under the examination. So we can start the evaluation of cleanness and development of method for the cleaning of them by ultrasonic cleaning and acid-alkali cleaning [3,4]. We will start the development in this year, and will report the result near future.

Thus progress of our development is going along quite smoothly. We can share the result of our development with preliminary examination team of Hayabusa2 sample analysis organized by Hayabusa2 project, and can make their start process faster.

In future work, we will develop the cutting method of samples with low-contamination processes, including sample mounting devices and handling method after the cutting. In order to include rare and trace element analysis using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) in our protocol, we will also start the development of sample holders and examination of it, in parallel with the rehearsals of the initial description of Hayabusa2 returned samples.

### References

- [1] Web page: <https://hayabusaa.isas.jaxa.jp/curation/release/index.html> (Japanese) [2] Uesugi M. et al. 2016. Abstract #1129-1100. Haybusa symp. 2016. [3] Karouji et al., 2014. Chikyū kagaku 48:211-220 (Japanese) [4] Ishibashi Y., Karouji Y., Fujimura A., Yada T., Uesugi M., Yakame S., Okada T., and Abe M. 2012. Asteroids, Comets, Meteors, abstract #6492

## Systematic detection of carbonaceous phases in chondrites – request for sophisticated techniques for Hayabusa 2 particle analyses

V.H. Hoffmann<sup>1,2</sup>, T. Mikouchi<sup>3</sup>, M. Kaliwoda<sup>4</sup>, R. Hochleitner<sup>4</sup>

<sup>1</sup>Fac. Geosciences, Dep. Geo- and Environmental Sciences, Univ. Munich, <sup>2</sup>Dep. Geosciences, Univ. Tübingen, Germany;

<sup>3</sup>Dep. Earth Planet. Science, Univ. Tokyo, Japan; <sup>4</sup>Mineralogical State Collection, Munich, Germany.

The Asteroid Explorer “Hayabusa 2” is the successor of “Hayabusa” (MUSES-C), which for the first time ever returned pristine samples from an asteroid [1]. 25143 “Itokawa” is a small Near-Earth S-type asteroid consisting mainly of ordinary chondrite type material [2, and refs herein]. The mission was a major step towards further elucidating the origin and formation of our solar system. The “Hayabusa 2” mission, launched in 2014, will target another Near-Earth asteroid, namely 162173 “Ryugu” (1999 JU3) which is a C-type asteroid. To learn more about the formation and evolution of our solar system, investigating different types of asteroids, namely S-, C-, and D-type, is mandatory. C-type asteroids such as “Ryugu” are interpreted as more primordial bodies than for example “Itokawa” and are considered to contain more carbonaceous, organic or hydrated mineral phases. Spectroscopical data show that this asteroid type might be closely related to primitive carbonaceous chondrites or comets in terms of material composition [3].

Very sophisticated techniques are required for the investigation of pristine “Ryugu” particles in our laboratories (return planned end of 2020). LASER Micro Raman Spectroscopy is perfectly suited for identifying and discriminating (extra-) terrestrial mineralogy: (a) fully non-destructive (repeated experiments possible on one and the same spot under variable conditions), (b) investigations with high sensitivity and in parallel high resolution, optionally in 3 dimensions, (c) as a major advantage experiments on pristine material without any preparation or coating, and (d) mineral polytypes (eg diamonds) can be well discriminated. Variable LASER frequencies allow to optimize and fine-tune the Raman system to specific sample and experiment requirements. High resolution scanning can produce very detailed distribution maps of selected mineral phases. Micron- or even nano-sized particles such as various diamond polytypes can be detected in this way. Within our Hayabusa sample analyses project we have successfully applied LASER Micro Raman Spectroscopy on several individual Itokawa particles [2].

Generally, the carbon-phase mineralogy has not really been investigated systematically in most meteorite types [4,5]. The main focus was on ureilites and certain carbonaceous chondrites [4-7], and priority was set on graphitic components and diamonds. The presence of very rare carbonaceous phases such as graphenes, fullerenes or nanotubes which can be expected in a number of meteorite types has not been investigated to our best knowledge. Therefore we have started detailed and systematic investigations on the carbon-phase mineralogy of a larger set of various stony meteorite types. Priority is presently set on the following selected recent falls and finds [8-13]: (a) Ordinary chondrites Machtenstein H5 (find around 1956, classified 2014), Braunschweig L6 (fall 2013), Stubenberg LL6 (fall 2016), and for comparison the HED meteorite Saricicek (howardite fall 2015) as well as a large series of Almahata Sitta individuals [polymict ureilite, 12,13 and refs]. In our poster we will present first detailed results concerning the carbon phase mineralogy in these meteorites and will also focus on hypotheses concerning the possible formation processes of the meteoritic micro-nano diamonds [6,7,14,15]: (a) Chemical Vapor Deposition (CVD) and (b) shock metamorphism as optional in situ diamond producing processes, and (c) presolar diamonds of extrasolar origin (eg from supernovae explosions).

### References

- [1] <http://global.jaxa.jp/projects/sat/hayabusa2/>: last visit 9/2017.
- [2] Mikouchi T. et al., 2014. Earth, Planets, Space, 66, pp82.
- [3] Norton R.O., 2002. The Cambridge Encyclopedia of Meteorites. Cambridge Univ. Press.
- [4] Ramdohr P., 1973. The opaque phases in stony meteorites. Elsevier, New York.
- [5] Makjanic et al., 1993. Meteor. 28, 63-70.
- [6] Szurgot M. et al., 2006. Nanodiam, PWN, Warszawa, pp259.
- [7] Karczewska A.T., 2010. J. Achievm. Mater. Man. Engineer. 43/1, 94-107.
- [8] <https://www.lpi.usra.edu/meteor/metbull.php>: last visit 9/2017.
- [9] Hochleitner R. et al., 2015. LPSC #2453.
- [10] Hochleitner R. et al., 2015. LPSC #1471.
- [11] Bischoff A. et al., 2017. Meteor. Planet. Sci. 1-21, doi: 10.1111/maps.12883.
- [12] Hoffmann et al., 2017. LPSC #2365.
- [13] Hoffmann et al., 2017. Metsoc #6290.
- [14] Gucsik et al., 2008. LPSC #1201.
- [15] Hus G.R., 2005. Elements 1, pp97-100.

# Preliminary results of Sulfur speciation by $\mu$ -XANES and STXM in Extraterrestrial Organics

Motoo Ito<sup>1</sup>, Ryoichi Nakada<sup>1</sup>, Hiroki Suga<sup>2</sup>, Takuji Ohigashi<sup>3</sup>, Yu Kodama<sup>4</sup> and Hiroshi Naraoka<sup>5</sup>

<sup>1</sup>Kochi Institute for Core Sample Research, JAMSTEC, <sup>2</sup>Hiroshima University

<sup>3</sup>UVSOR Synchrotron, Inst. Mol. Sci., <sup>4</sup>Marine Works Japan, <sup>5</sup>Kyushu University

Sulfur is one of the major elements in terrestrial and extraterrestrial organics. The elemental compositions of the Murchison IOM (insoluble organic matter) are proposed to be  $C_{100}H_{70}O_{22}N_3S_7$  [1] or  $C_{100}H_{48}N_{1.8}O_{12}S_2$  [2]. Because sulfur shows a wide range in oxidation state (-2 to +6) with both electropositive and electronegative elements, both reduced and oxidized sulfur species have been found in various carbonaceous chondrites [3, 4]. Therefore, understanding of speciation of sulfur and its distribution within organics in a carbonaceous chondrite is crucial to provide the secondary alteration processes of thermal metamorphism and aqueous alteration in the parent body.

X-ray absorption near edge spectroscopy (XANES) is a powerful analytical tool to characterize and quantify chemical speciation, functional group and bonding environment of the sample. In the field of cosmochemistry, many researches were carried out to identify functional groups of C, N and O in extraterrestrial organics (i.e., IOM in carbonaceous chondrites [5], cometary returned sample [6], organics found in Hayabusa Category-3 grains [7], organics in IDPs [8]). However, sulfur study with XANES in the extraterrestrial organics is very rare [3, 9].

In this study, we report preliminary results of sulfur speciation measurements by K- and  $L_3$ -edge XANES of the IOM extracted from Asuka 881458 CM2 carbonaceous chondrite. We carried out X-ray fluorescence (XRF) mapping for S and N with a spatial resolution of 20  $\mu\text{m}$  in the IOM ( $0.8 \times 1 \text{ mm}^2$ ) at BL27SU of SPring-8. We, then, conducted  $\mu$ -XAFS (sulfur K-edge) measurements to acquire point spectra (#1-#6 in Fig. 1). In addition, we have measured carbon K-edge and sulfur  $L_3$ -edge XANES spectra in the FIB section of the AA881459 IOM ( $8 \times 20 \mu\text{m}^2$ ) using scanning transmission X-ray microscope (STXM) at Inst. Mole Sci. UVSOR BL4U.

Figure 1 shows S and N XRF images together with optical microscope image of the sample on the Si wafer. The distributions of S and N are similar but slightly different abundances. We used these images to determine XANES analysis spots in the sample (about 20  $\mu\text{m}$  in size, #1 to #6 in Figure 1).

Measured S K-edge XANES spectra (#1 to #6) have deconvoluted with a least-square linear combination best fits to reference spectra of S contained organic and inorganic compounds. Figure 2 shows a radar diagram of possible S components and their abundances in each spot (#1-#6). Each spot has different sulfur contained organics and inorganics and their abundances. This suggested that extraterrestrial organics is a complex mixture of several types of sulfur species. Our result is consistent with previous works [3, 9]. S  $L_3$ -edge XANES spectra of several S-contained organics with different species (lauryl sulfate, sodium methanesulfonate, L-cysteic acid and DL-methionine sulfone) were obtained as references. Figure 3 shows high-resolution (50 nm) S  $L_3$ -edge STXM image of the FIB section of the AA881459 IOM. It is noted that S is homogeneously distributed and tiny S hot spots were observed within the sample. However, it is difficult to deconvolute the  $L_3$ -edge spectra of the sample based on fitting by a linear combination of standard materials spectra because of lack of the S  $L_3$ -edge spectra for reference materials at this moment.

Figure 1. S and N XRF images of extracted organics from A881458 CM2 chondrite.

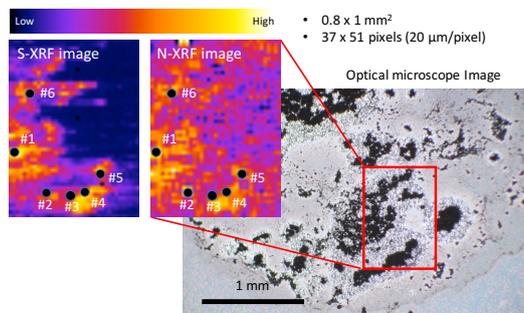


Figure 2. Possible sulfur components in the extracted organics from A881458 obtained by K-edge spectrum.

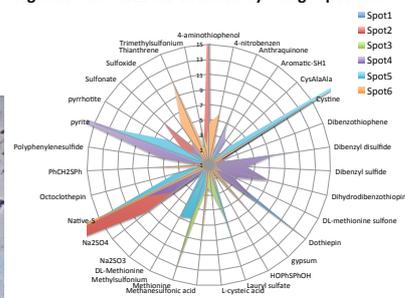
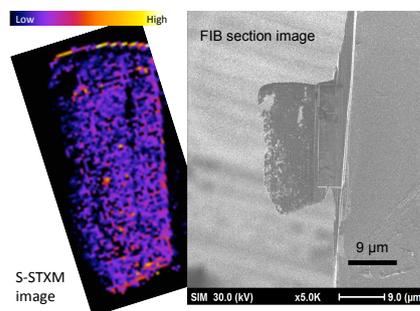


Figure 3. Sulfur  $L_3$ -edge STXM image and SIM image



**References:** [1] Remusat, 2011. EPJ Web of Conferences 18:05002. [2] Gilmour, 2005. In Meteorites, comets and planets, Treatise on Geochemistry, p.269. [3] Orthous-Daunay et al. 2010. EPSL, 300, 321–328. [4] Cooper et al. 1997. Science, 277, 1072–1074. [5] Cody et al. 2011. Meteor Planet Sci 43:353–365. [6] Sanford et al. 2006. Science, 314:1720–1724. [7] Yabuta et al. 2014. EPS, 66, 156. [8] Flynn et al. 2003. Geochim Cosmochim Acta, 67, 4791–4806. [9] Bose et al. (2017) Meteor Planet Sci, 52, 546–559.

# The evolution of water-rich asteroids: Linking the mineralogy and spectroscopy of fully hydrated CM carbonaceous chondrites

Helena Bates<sup>1,2</sup>, Ashley King<sup>1</sup>, Kerri Donaldson Hanna<sup>2</sup>, Neil Bowles<sup>2</sup> and Sara Russell<sup>1</sup>

<sup>1</sup>*Mineral and Planetary Sciences Division, Natural History Museum, London, SW7 5BD, UK*

<sup>2</sup>*Atmospheric, Oceanic and Planetary Physics, University of Oxford, Oxford, OX1 3PU, UK*

**Introduction:** The C-complex asteroids (which include B, C, F and G-types [1]) are of interest because they are thought to be volatile-rich, and may be able to tell us about the evolution of water and organic compounds in the early Solar System. Additionally, C-complex asteroids likely made a significant contribution to the volatile budget of the terrestrial planets [2,3]. Carbonaceous chondrite meteorites are physical samples of C-complex asteroids; linking laboratory spectra of carbonaceous chondrites to remote sensing observations of asteroids can therefore give insight into the processes, which occur on primitive bodies in the Solar System.

Spectrally, many C-complex asteroids show evidence for aqueous alteration and links with CM and CI carbonaceous chondrites on their surfaces [4–7]. Most spectral links have been between the C-complex asteroids and moderately altered CM2 chondrites. Although there have been limited studies on the association of these asteroids with fully hydrated (“type 1”) chondrites, Clark et al. [8] suggested a possible relationship between more aqueously altered CM and/or CI chondrites and the surface mineralogy of the B-type, OSIRIS-REx target asteroid, Bennu.

The CM1 chondrites are among the most hydrated extra-terrestrial materials available to study; their precursor mineral assemblages have been almost entirely transformed into secondary, hydrated phases. King et al. [9] investigated CM1 and CM1/2 chondrites with the aim of establishing modal mineralogy and examining variations in the extent of aqueous alteration. In this study we collected reflectance spectra from the same powders used by King et al. [9] so that any spectral trends could be put into context of the mineralogy and degree of aqueous alteration for each meteorite sample.

**Experimental:** The suite of meteorites investigated included six CM1/2 chondrites and four CM1 chondrites. Approximately 100 mg of each sample was ground into a fine powder using an agate mortar and pestle to a particle size of <35  $\mu\text{m}$ . Infrared reflectance spectra of the powders were obtained using a Bruker VERTEX 70v Fourier Transform Infrared (FTIR) spectrometer at the University of Oxford, using a wide range MIR-FIR beam splitter and a room temperature deuterated L-alanine doped tryglycine sulfate (RT-DLaTGS) detector to measure the reflectance between 6000 - 200  $\text{cm}^{-1}$  (1.7-50  $\mu\text{m}$ ). All observations were obtained under vacuum ( $\sim 5$  hPa), at a resolution of 4  $\text{cm}^{-1}$ . In order to remove instrumental effects, spectra were calibrated by dividing each meteorite spectrum with a spectrum of a gold calibration target,

**Results & Discussion:** Initial observations of the mid-infrared spectra show samples, which are mostly composed of hydrated minerals, particularly serpentine-group phyllosilicates. Upon further investigation of individual spectral regions - the 3  $\mu\text{m}$  band, 6  $\mu\text{m}$  band, Christiansen features (CF: 7.5-9.5  $\mu\text{m}$ ), and the transparency features (TF: 10.5-14  $\mu\text{m}$ ) - different phyllosilicate compositions and abundances resulted in different, distinguishable spectral features.

The 3  $\mu\text{m}$  band centres are affected by the Fe-cronstedtite abundances in the samples, with higher abundances shifting the feature to longer wavelengths. The 6  $\mu\text{m}$  band features appear to reflect the anhydrous silicate content, with greater band depths for higher olivine contents. The CFs are identified at similar wavelength positions for all samples (8.8 - 8.9  $\mu\text{m}$ ) suggesting the meteorites have similar bulk mineralogy. The TFs were affected by the total phyllosilicate abundance, with higher abundances shifting the peaks to shorter wavelengths.

The above conclusions resulted in splitting the meteorites into two groups. Group A samples had larger 6  $\mu\text{m}$  band features, a 3  $\mu\text{m}$  band centre, and TF peak at longer wavelengths ( $\sim 2.8$   $\mu\text{m}$  and  $\sim 12.5$   $\mu\text{m}$  respectively). Group B samples had smaller 6  $\mu\text{m}$  band features, a 3  $\mu\text{m}$  band centre, and TF peak at shorter wavelengths ( $\sim 2.7$   $\mu\text{m}$  and  $\sim 11.6$   $\mu\text{m}$  respectively).

Group A samples represent the least altered CM1/2s, which have significant Fe-cronstedtite abundances of 30.8 – 36.9% and anhydrous olivine abundances of 18.2 – 19.6%. Group B samples represent the most altered CM1s, which have significant Mg-serpentine (52.4 – 71.6%) and low olivine abundances (3.6 – 8.0%). This study shows that slight variations in aqueous alteration might be discernible in current and future telescopic and space mission observations of C-complex asteroids.

**References:** [1] Tholen, D.J., 1984. [2] Alexander, D. et al., 2012 *Science*, 721. [3] Alexander, C.M.O., 2017 *Philosophical Transactions of the Royal Society*, 375. [4] Fornasier, S. et al., 1999 *Astron. Astrophys. Suppl. Ser.*, 135:65. [5] Ziffer, J. et al., 2011 *Icarus*, 213: 538. [6] Cloutis, E.A. et al., 2011 *Icarus*, 216:309. [7] Takir, D. et al., 2015 *Icarus*, 257:185. [8] Clark, B.E. et al., 2011 *Icarus*, 216:, 462. [9] King, A.J., P.F. Schofield, S.S. Russell, 2017 *Meteoritics & Planetary Science*, 52:1197.

### **Current status of consortium study of silica-containing Hayabusa-returned particle.**

M. Hashiguchi<sup>1</sup>, A. Miyake<sup>2</sup>, A. Tsuchiyama<sup>2</sup>, T. Nakamura<sup>3</sup>, M. Uesugi<sup>4</sup>, J. Matsuno<sup>2</sup>, A. Nakato<sup>2</sup>, T. Yada<sup>5</sup>, M. Yoshitake<sup>5</sup>, T. Okada<sup>5</sup>, M. Abe<sup>5</sup>, and H. Yurimoto<sup>5,6</sup>.

<sup>1</sup>PTOC, Kyushu University (hashiguchi.minako.123@m.kyushu-u.ac.jp), <sup>2</sup>Department of Geology and Mineralogy, Graduate School of Science, Kyoto University, <sup>3</sup>Department of Earth Science, Tohoku University, <sup>4</sup>JASRI, SPring-8, <sup>5</sup>ASRG, JAXA, <sup>6</sup>Natural History Sciences, Hokkaido University.

**Introduction:** About 730 particles of Hayabusa-returned sample of 10 to 300  $\mu\text{m}$  size are collected by Extraterrestrial Sample Curation Center (ESCuC) in Astromaterials Science Research Group (ASRG) of JAXA, so far [1]. The preliminary examinations and international AOs revealed that Itokawa particles were equivalent to equilibrated LL chondrites [e.g. 2-10]. Some of the Hayabusa-returned particles show unique characteristics including mineralogy, composition, structure, and/or size. Therefore, consortium studies have been conducted by team of ESCuC in order to obtain maximum scientific results from such particles [11-13].

We proposed a new consortium study of particle RB-QD04-0069 containing silica [14]. This is the only particle which contains silica coexist with other silicate minerals among catalogued Hayabusa-returned samples, so far. Silica is widespread in ordinary chondrites, but its abundance is very low (usually  $< \sim 1$  vol %) [15]. Therefore, the particle RB-QD04-0069 is precious and it should be investigated as consortium study. Evidence of shock processes have been revealed from Hayabusa-returned particles by previous studies and shock and/or thermal history of the particles were discussed [2, 8-10]. Because silica has many polymorph, it should be useful indicator to constrain thermal and/or shock history of the particle [16]. In this paper, we report current status of the consortium study of particle RB-QD04-0069.

**Sample and Analytical flows:** RB-QD04-0069 is a particle with a size of 33  $\mu\text{m}$ , which was captured from the first touchdown site on Itokawa. The particle consists of olivine, high-Ca pyroxene, low-Ca pyroxene, plagioclase, and silica revealed by initial description by FE-SEM-EDS.

The XRD analysis will provide us crystallographic information of silica and other silicate minerals. Moreover, textural information of the particle will be obtained by the SR XCT imaging. After the synchrotron radiation analyses, the particle will be embedded in epoxy resin EPON-812, followed by polishing until the surface of the particle is exposed. Then, oxygen isotope compositions will be measured by SIMS in order to identify the origin of the particle. Furthermore, FE-EMP analysis and TEM observations will be carried out on the particle to obtain important constraints on formation condition of the particle, especially its shock and thermal history.

**Current status:** The particle RB-QD04-0069 was picked up from a slide glass in pure nitrogen-filled environment clean chamber in ESCuC by quartz glass probe using manipulator system last year. Then, the particle was tried to attach to the top of C fiber with epoxy resin Embed-812 using manipulator system in a clean booth at ESCuC for Synchrotron radiation (SR) XRD analysis and SR XCT imaging. However, during the procedure, the particle RB-QD04-0069 was failed to attach to C fiber and fell down on the slide glass or Al foil on heater used for the handling.

By optical microscope and SEM-EDS analysis, three candidate particles were found from Al foil on the heater. We plan to analyze these candidate particles by detailed FESEM-EDS to narrow down the candidates. Then, the surrounding region (Al foil) of the candidates will be cut by FIB at Kyoto University and attach them to C fiber using Pt depo for SR-XRD and XCT analysis to identify true particle using characteristics of silica, olivine, pyroxene, and plagioclase.

**References:** [1] Yada T. et al. (2017) 80th MetSoc, #6204. [2] Nakamura T. et al. (2011) Science 333, 1113. [3] Yurimoto H. et al. (2011) Science 333, 1116. [4] Ebihara M. et al. (2011) Science 333, 1119. [5] Noguchi T. et al. (2011) Science 333, 1121. [6] Tsuchiyama A. et al. (2011) Science 333, 1125. [7] Nagao K. et al. (2011) Science 333, 1128. [8] Zolensky M. et al. (2012) LPS XLIII #1477. [9] Mikouchi T. et al. (2014), EPS, 66, 82 [10] Harries D. et al. (2016) EPSL, 337. [11] Yada T. et al. (2014) LPS XLIV #1759. [12] Uesugi M. et al. (2014) 77th Ann. Meeting Meteorit. Soc., #5226. [13] Karouji Y. et al. (2014) 77th Ann. Meeting Meteorit. Soc., #5240. [14] Hashiguchi M. et al. (2015) 78th MetSoc, #5193. [15] Hezel D. et al. (2006) GCA, 70, 1548. [16] Swamy V. et al., (1994) J. Geophys. Research. 99, 787.